Vilnius CCD Photometry of Southern Clusters:
Some Preliminary Results

Timothy Banks, D.J. Sullivan, M.C. Forbes,

Department of Physics, Victoria University of Wellington, P.O. Box 600, Wellington

and

R.J. Dodd,

Carter Observatory, P.O. Box 2909, Wellington.

Abstract

The Vilnius Photometric system has been used with a CCD system only once before this study. Preliminary crowded field reductions of Vilnius CCD observations of the star clusters NGC 2004 and NGC 4755 (the κ Crucis cluster) are presented, demonstrating the feasibility of using the filter set in this manner given the resources available to Victoria University of Wellington. The standard (photo-electric) filters were used for the first time in conjunction with a CCD system. It is also the first time this filter system has been applied to an extra-galactic star cluster (NGC 2004).

1   Introduction

The seven filter Vilnius system (see Straižys 1992a, Forbes 1993) makes possible the purely photometric determination of the spectral classes, absolute magnitudes, and metallicities of stars while also correcting for interstellar reddening. This is facilitated by the careful thought given to the positioning and widths of the filters relative to the spectral features of all luminosity classes. For example, the U filter measures the ultraviolet intensity below the Balmer jump, while the P filter is placed on the jump itself, allowing luminosity determinations for early type stars. The Z, V and S filters coincide with features in late-type stars (see Figure 1 of Dodd, Forbes & Sullivan 1993). Peculiar stars, such as metal-deficient Giants and blue Horizontal Branch stars, can be recognized using the two and three dimensional classification schemes of the system (Straižys 1992b), making the filter set well suited for the study of star clusters. Further details of the rationale in the design of the filter set may be found in Straižys & Sviderskiene (1972). Figure 1 plots the response functions for the Vilnius filters in combination with the Mount John University Observatory (MJUO) CCD.

In light of these capabilities, the idea of extending the system to the southern hemisphere was first considered in 1985 at the Royal Observatory Edinburgh, given that none of the already established standard regions (e.g. Zdanavičus *et al.* 1969, Černies *et al.* 1989, and Černies & Jasevičus 1992) extended south of the celestial equator. This programme commenced in 1988 using the 61cm telescopes at MJUO, with the initial goal of establishing

1

Figure unavailable in machine readable form

Figure 1: **Vilnius Filter Response for the TH7882 Chip:** Measured transmittances of the Vilnius filters, and the Manufacturer's Quantum Efficiency specifications for the TH7882 CCD used in this study (given as a dotted line), were combined to show the filter responses with this chip. For a flat spectrum, the percentage transmittances of the U, P, X, Y, Z and S filters relative to V are 61, 53, 74, 95, 106 and 87 respectively.

standards near the South Celestial Pole and also bright (V < 7) stars generally distributed south of -20 degrees. To date some 90 cluster, 109 primary standard, and 225 secondary standard stars have been observed at least once. Further details on the programme may be found in Forbes (1993) and Forbes, Dodd & Sullivan (1993). Given this network, and the availability of both an established image reduction system and medium size telescope equipped with a CCD, test images were acquired of the open (Galactic) cluster NGC 4755 and the LMC young "globular" NGC 2004.

2   Observations

Vilnius photometry has been realised with a CCD only once before, in the cursory trial of Boyle *et al.* (1990) who used a non-standard filter set. The objective of the current study was to determine if useful observations could be obtained using the Vilnius filters in conjunction with the MJUO CCD camera and associated hardware.

UPYV observations were made on March 5 1993 with the 1m McLellan telescope at MJUO (170° 27^{m}9 East, 43° 59$'$2 South) in $\sim 3''$ seeing, using a cryogenically cooled Thomson TH7882 CDA charge-coupled device. This chip has 384 by 576 pixels. Each pixel is 23 μm across, which at the f/7.9 Cassegrain focus used by this study corresponds to $0.60''$ (Tobin 1989). Images were collected using the Photometrics PM-3000 computer running FORTH (Moore 1974) software with extensive local modifications, and written to half inch 9 track magnetic tape for transportation back to Victoria University of Wellington (VUW) for analysis. Images from these tapes were then converted into the FITS (Wells, Griesen & Harten 1981) format from the native Photometrics one, and read into the Image Reduction

and Analysis Facility (IRAF)[1], where subsequent reduction took place. Details on the data pathway and Image processing facility established at VUW are in Banks (1993). Further details on the MJUO CCD data acquisition system and its characteristics may be found in Tobin (1992).

2.1   NGC 2004

NGC 2004 is a young (~ 8 x 10^7 years according to Hodge 1983) populous star cluster in the Large Magellanic Cloud, making it an attractive object for the study of stellar evolution models. Several studies have derived Johnson BV Colour Magnitude Diagrams (CMDs) for it, including Bencivenni *et al.* (1991), and Balona & Jerzykiewicz (1993). Figure 2(a) gives the Vilnius YV CMD based on 19.1 minute exposures standardized using observations of 9 different primary standards over an airmass range of 1.5 to 2.3. The unusual exposure lengths are due to the Photometrics Acquisition System running 4.3% fast for some exposure commands (Tobin 1991). Unfortunately, clouding in the early morning led to other collected observations of standards being rejected. This development of cloud took place during the NGC 4755 observations. The standardization equations:

$$V_o = V + (18.00 \pm 0.05) + ((-0.071 \pm 0.024) \text{ x } (Y - V)) + ((0.262 \pm 0.028) \text{ x Airmass})$$

and

$$Y_o = Y + (18.08 \pm 0.05) + ((-0.028 \pm 0.021) \text{ x } (Y - V)) + ((0.273 \pm 0.029) \text{ x Airmass})$$

were obtained using the IRAF Photcal package, and are only preliminary. They will be recalculated when values for the secondary standard BS4293 (which was observed at low airmass several times early in the night) are produced by the standards programme. The root mean squares for both the transformation equations are 0.02 mag. The transformations for the U and P observations are currently being derived.

The major features of this CMD are the near vertical and well defined Main Sequence (MS), a few evolved stars in a red giant clump around V $\sim$ 13 and (Y $-$ V) $\sim$ 1.4, and the field evident at the fainter magnitudes to the red of the MS. These features, and their relative densities, are identical to those seen in the literature (see e.g. Elson 1991 for a BV CMD acquired with a 1m telescope equipped like the MJUO 1m). The stars to the blue of the MS are artifacts of the crowded field reduction and the poor observing conditions. The widening of the MS towards the fainter magnitudes is a good reflection of the photometric errors (see Mateo & Hodge 1987). Direct comparison between the CMD presented and literature Johnson BV CMDs is aided by the fact that the Vilnius V coincides with the Johnson V magnitude for all unreddened or slightly reddened stars of spectral types O to K and all luminosity classes (p489, Straižys 1992a).

2.2   NGC 4755

It was originally intended to use the secondary standards in this cluster, in conjunction with the low altitude primary standards, to derive the transformation equations. When observed,

---

[1] Courtesy of the National Optical Astronomical Observatories, which are operated by the Association of Universities for Research in Astronomy under cooperative agreement with the National Science Foundation.
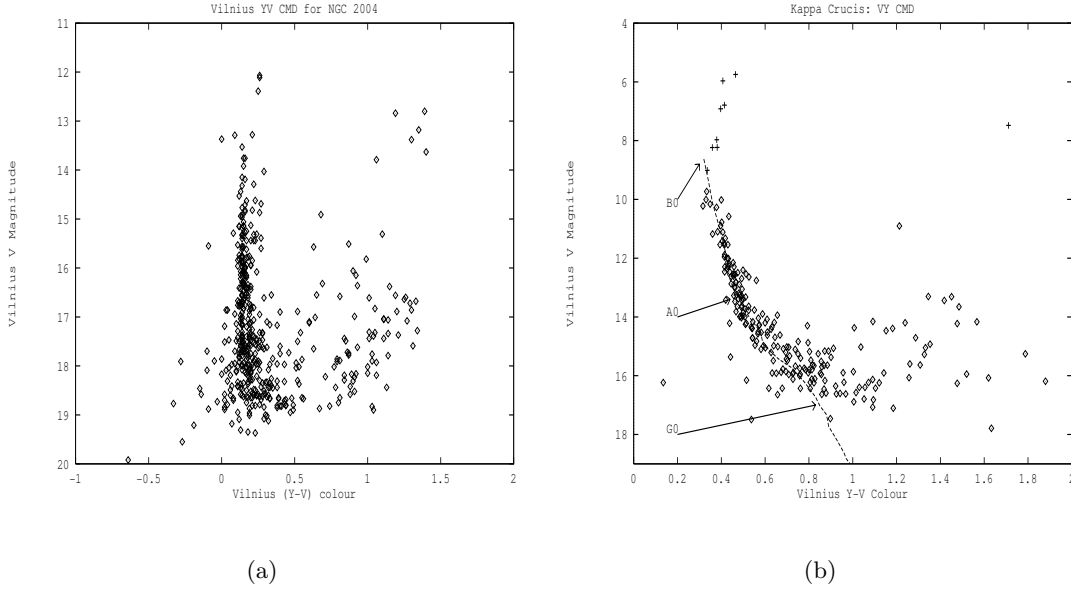
Figure 2: **Colour Magnitude Diagrams for NGC 2004 and NGC 4755:** Subfigure (a) is the standardized, aperture corrected Vilnius YV CMD for the LMC cluster NGC 2004. Subfigure (b) is the YV CMD for NGC 4755 standardized by direct comparison with established Vilnius secondary standards in the field of the CCD Images. The plus symbols are photo-electric observations taken from Forbes (1994). The dashed line is the Main Sequence as given in Straižys (1992a), taking into account a 11.85 mag distance modulus and interstellar reddening E(B-V) of 0.40 mag (Kjeldsen & Frandsen 1991). A similar fit will be made to NGC 2004 once E(B-V) is determined from a colour-colour diagram. Both CMDs were derived using the IRAF implementation of the "Classic DAOphot" (Stetson 1987) crowded field reduction software.

the cluster standards were at low airmasses. Unfortunately, the above mentioned formation of cloud prevented this, forcing the use of a direct transformation based on the "on chip" local standards. The root mean square errors for the Y and V transformations are large, being 0.03 and 0.05 mag respectively. The large uncertainties are at least partially due to the brighter, and more frequently measured, standards being saturated or approaching pixel saturation, and so the fainter and less frequently measured stars being used. The standard deviations, and their uncertainties, based on the formal errors of the standard stars themselves (as given by Forbes 1994) are 0.04 and 0.04 mag for the Y and V passbands respectively. Figure 2(b) shows a YV CMD based on 3.2 and 0.8 minute exposures. It agrees well with the CMDs of Shobbrook (1984), Dachs & Kaiser (1984), Slettebak (1985), and Frandsen, Dreyer & Kjeldsen (1989). The unusually placed star at V $\sim$ 11 and Y-V $\sim$ 1.2 is star number 104 in Dachs & Kaiser (DK), with a (V, B-V) of (11.03, 1.57), which they excluded as an unlikely member of the cluster. The bright red star (V$\sim$ 7.5, Y-V$\sim$ 1.7) is designated in the DK scheme as D. This star (κ Crucis itself) was used as the centre of the Images taken, since it is effectively in the centre of the cluster.

4

3 Discussion

This preliminary work has demonstrated that the recently acquired 28mm diameter Vilnius filters allow the use of the MJUO CCD image acquisition system, and the established data reduction pathway at VUW, to produce Vilnius photometry in line with the literature. An unanticipated problem was encountered with the substantially different thicknesses of the Vilnius filters, ranging from 9.79 to 3.26 mm, and the difficulty of ensuring that both the telescope and the offset guider were in focus for the individual filters. The focus of the guider is relative to that of the telescope. When the telescope was refocused to account for the different thicknesses of the filters, the guider was taken out of focus and had to be adjusted. Use of the offset guider is essential if faint limiting magnitudes are to obtained with the Vilnius system (see Figure 1 for the combined response of the filters and the CCD). The solution to this problem is to ensure that all the filters are of the same optical depth, removing the need to change focus between the filters. It is intended to use Schott FK5 glass to build the P and X filters up to the depth of the thickest filter (U), and B270 for the remainder. The spectral profiles and transmittances of the filters should not be significantly altered by these additions.

Given that the feasibility of the Vilnius filters with the MJUO CCD system has been demonstrated, it is intended to use the Vilnius system in further observations of star clusters, and in particular the populous LMC ones.

4 Acknowledgments

5 References

Balona, L.A., & Jerzykiewicz, M., 1993, *Monthly Notices of the Royal Astronomical Society*, **260**, 782.

Banks, T., 1993, *Southern Stars*, **35**, 33.

Bencivenni, D., Brocato, E., Buonanno, R., & Castellani, V., 1991, *Astrophysical Journal*, **102**, 137.

Boyle, R.P., Smriglio, F., Nandy, K., & Straižys, V., 1990, *Astronomy & Astrophysics Supplement Series*, **84**, 1.

Černies, K., Meištas, E., Straižys, V., & Jasevičius, V., 1989, *Bulletin of the Vilnius Observatory*, **84**, 9.

Černies, K., & Jasecvičus, V., 1992, *Baltic Astronomy*, **1**, 83.

Dachs, J., & Kaiser, D., 1984, *Astronomy & Astrophysics Supplement Series*, **58**, 411.

Dodd, R.J, Forbes, M.C., & Sullivan, D.J, 1993, *Stellar Photometry — Current Techniques and Future Developments*, IAU Colloquium #136, Eds: C.J. Butler & I. Elliot, Cambridge University Press, Cambridge, 51

Elson, R.A.W., 1991, *Astrophysical Journal Supplement Series*, **76**, 185.

Forbes, M.C., 1993, *Southern Stars*, **35**, 69.

Forbes, M.C., 1994, *Unpublished PhD Thesis*, Victoria University of Wellington.

Forbes, M.C., Dodd, R.J., & Sullivan, D.J., 1993, *Baltic Astronomy*, **2**, 246.

Frandsen, S., Dreyer, P., & Kjeldsen, H., *Astronomy & Astrophysics*, **215**, 287.

Hodge, P.W., 1983, *Astrophysical Journal*, **264**, 470.

Kjeldsen, H., & Frandsen, S., 1991, *Astronomy & Astrophysics Supplement Series*, **87**, 119.

Mateo, M., & Hodge, P.W., 1987, *Astrophysical Journal*, **320**, 652.

Moore, C.H., 1974, *Astronomy & Astrophysics Supplement Series*, **15**, 497.

Shobbrook, R.R., 1984, *Monthly Notices of the Royal Astronomical Society*, **206**, 273.

Slettebak, A., 1985, *Astrophysical Journal Supplement Series*, **59**, 769.

Stetson, P.B., 1987, *Publications of the Astronomical Society of the Pacific*, **99**, 191.

Straižys, V., 1992a, *Multicolour Photometry*, Volume 15 of "Astronomy and Astrophysics Series", Pachart Publishing House, Tucson, Arizona.

Straižys, V., 1992b, *Baltic Astronomy*, **1**, 107.

Straižys, V., & Sviderskiene, Z., 1972, *Astronomy & Astrophysics*, **17**, 312.

Tobin, W., 1989, in *"Recent Developments of Magellanic Clouds Research"*, Eds: K.S. de Boer, F. Spite, and G. Stanska, Observatoire de Paris, 177.

Tobin, W., 1991, *Mount John CCD System and Performance Note # 7*.

Tobin, W., 1992, *Southern Stars*, **34(8)**, 421.

Wells, D. C., Griesen, E. W., & Harten, R. H., 1981, *Astronomy & Astrophysics Supplement Series*, **44**, 363.

Zdanavičus, K., Sūdžius, J., Sviderskienė, Z., Straižys, V., Burnašov, V., Drazdys, R., Bartkevičius, A., Kakaras, G., Kavalianskaite, G., & Jasevičius, V., 1969 *Bulletin of the Vilnius Observatory*, **26**, 3.

This figure "fig1-1.png" is available in "png" format from:

http://arXiv.org/ps/astro-ph/9410087v1